Return to Sports Participation After Articular Cartilage Repair in the Knee

Scientific Evidence

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Background: Articular cartilage injury in the athlete's knee presents a difficult clinical challenge. Despite the importance of returning injured athletes to sports, information is limited on whether full sports participation can be successfully achieved after articular cartilage repair in the knee.

Hypothesis: Systematic analysis of athletic participation after articular cartilage repair will demonstrate the efficacy of joint surface restoration in high-demand patients and help to optimize outcomes in athletes with articular cartilage injury of the knee.

Study Design: Systematic review.

Methods: A comprehensive literature review of original studies was performed to provide information about athletic participation after articular cartilage repair. The athlete's ability to perform sports postoperatively was assessed by activity outcome scores, rate of return to sport, timing of the return, level of postoperative sports participation, and the continuation of athletic activity over time.

Results: Twenty studies describing 1363 patients were included in the review, with an average follow-up of 42 months. Return to sports was possible in 73% overall, with highest return rates after osteochondral autograft transplantation. Time to return to sports varied between 7 and 18 months, depending on the cartilage repair technique. Initial return to sports at the preinjury level was possible in 68% and did not significantly vary between surgical techniques. Continued sports participation at the preinjury level was possible in 65%, with the best durability after autologous chondrocyte transplantation. Several factors affected the ability to return to sport: athlete's age, preoperative duration of symptoms, level of play, lesion size, and repair tissue morphology.

Conclusion: Articular cartilage repair in the athletic population allows for a high rate of return to sports, often at the preinjury level. Return to sports participation is influenced by several independent factors. The findings provide pertinent information that is helpful for the clinical decision-making process and for the management of the athlete's postoperative expectations.

Keywords: sport; athletics; cartilage; articular; injury; repair; resurfacing; chondroplasty; knee

Increasing participation in recreational and competitive sports has been associated with a growing incidence of sports-related articular cartilage injuries of the knee.[9,28,34,43] These injuries frequently occur in association with other knee injuries and have been described in up to 50% of athletes undergoing anterior cruciate ligament (ACL) reconstruction.[9,11,43] Based on the reported incidence of 200 000 ACL injuries each year, up to 100 000 new articular cartilage injuries are estimated to result in this population alone, emphasizing the epidemiological relevance of these injuries.[3,20] Whereas athletes with articular cartilage injury may initially be able to return to their sport, a significant decline of athletic activity has been observed over time, with significant reduction of athletic ability, marked lifestyle modifications, and radiographic evidence of osteoarthritis in many of these athletes.[34] Correspondingly, several independent studies have demonstrated up to a 12-fold

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increased risk for knee osteoarthritis in high-demand, pivoting athletes.[10,12,27] Because of the forceful, repetitive joint loading in impact sports, joint surface restoration in the athlete's knee presents a significant therapeutic challenge and requires a repair cartilage that can withstand the significant mechanical joint stresses generated during sports activity. Current cartilage repair techniques, such as microfracture, osteochondral autograft transfer, osteochondral allograft transplantation, and autologous chondrocyte transplantation, have shown promising results in reducing pain and improving knee function scores and have created considerable clinical and scientific enthusiasm in articular cartilage repair.[22,23,29] Despite the fact that postoperative return to sports presents the most important measure of successful outcome for the injured athletes, comprehensive information is not available on sports participation after cartilage repair in the athletic population. We therefore systematically investigated the efficacy of established articular cartilage repair techniques to improve postoperative activity scores and to return athletes to demanding sports activity and continued sports participation. Furthermore, we aimed to identify the factors that can influence the ability of the athlete to participate in demanding sport activity after articular cartilage repair.

MATERIALS AND METHODS

We performed a comprehensive search of the English literature to identify any published and unpublished clinical studies on cartilage repair in athletes using the following medical electronic databases: MEDLINE, MEDLINE preprints, EMBASE, CINAHL, Life Science Citations, and the British National Library of Health, including the Cochrane Central Register of Controlled Trials (CENTRAL). The search period was January 1, 1966, to May 31, 2009. The medical databases were searched using the terms *sport*, *athlete*, *return to sport*, *athletic activity*, *chondral defect*, *condylar lesion*, *condyle lesion*, *patellofemoral lesion*, *trochlear defect*, *knee lesion*, *joint surface defect*, *JSD*, *articular resurfacing*, *articular cartilage repair articular resurfacing*, *chondroplasty*, *microfracture*, *marrow stimulating technique*, *osteochondral transfer*, *autograft*, *allograft*, *OATS*, *mosaicplasty*, *chondrocyte transplantation*, *cartilage transplantation*, *autologous chondrocyte implantation.* In addition, the bibliographies from the identified studies and from reviews on articular cartilage repair were manually searched. Abstract books of recent relevant scientific meetings were also searched. Any study reporting clinical information on sports activity after articular cartilage repair in the athlete was selected for primary review. Attention was placed on identifying studies that described sports activity–related functional outcome scores, the ability to return to sports after surgery, and the ability to continue participation in athletic activity over time.

We identified 141 clinical studies reporting on articular cartilage repair and athletics. Cartilage repair techniques included microfracture, osteochondral autograft transfer (mosaicplasty), osteochondral allograft transplantation, and autologous chondrocyte transplantation. Studies on autologous chondrocyte transplantation included first-generation technique, characterized chondrocyte transplantation, and second-generation techniques (Hyalograft C). The abstracts of these studies were evaluated in a primary screening process that included only studies reporting on International Cartilage Repair Society grade III or IV chondral or osteochondral defects of the knee (femoral condyle, tibia, and patellofemoral). Studies reporting on individual cartilage repair procedures or comparing different surgical techniques were included. Given that cartilage injuries in athletes frequently occur in association with other injuries, studies with or without concomitant injuries and procedures were included. All prospective randomized controlled studies (level 1 and 2) were included in the study if they provided information on sports participation after articular cartilage repair in the knee. Prospective or retrospective studies with or without control groups (level 3 and 4) were accepted for inclusion into the study if they provided postoperative follow-up data 2 years or more after the index surgery. Studies providing macroscopic or histologic data obtained at second-look arthroscopy more than 12 months after surgery were also included.

Twenty-five studies met these primary inclusion criteria and were carefully reviewed in a secondary screening process. After secondary review, 4 studies were excluded because they reported on less than 20 patients, and 1 study was excluded for a follow-up rate of less than 80% (Appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/). The modified Coleman methodology scores and subscales were determined to assess the methodological quality of each included study.[8,19] In addition, we systematically extracted data on study characteristics and design, level of evidence, demographic parameters, cartilage defect characteristics, surgical technique, associated surgical procedures, and clinical follow-up. Focus was placed on extracting data describing measures of sports participation after articular cartilage repair, such as activity scores, rate of return to sport, time of return to sports activity, level of postoperative sports participation, and continuation of sports participation at the preinjury level. The Lysholm-Gillquist score, Tegner activity scale, and Knee injury and Osteoarthritis Outcome Score (KOOS) were included as outcome measures because they have been evaluated for articular cartilage repair in the knee or include specific sport activity information.[18,24] In addition, macroscopic and histological data of the repair cartilage in athletes were collected when available from the reviewed studies.

The collected data were analyzed using established statistical software. Differences between independent parameters were evaluated using the Kruskall-Wallis test. Relationships between variables were tested by using the Pearson correlation coefficient (r). Differences between variable proportions were measured by chi-square analysis. Differences were considered significant with a $P < .05$. Data are presented as mean $\pm$ standard error of the mean.

RESULTS

Twenty studies describing 1363 patients were included in this systematic review. Average postoperative follow-up

was 42 ± 3 months (range, 18-84 months). The mean number of patients was 61 ± 10 (range, 20-236 patients). Defect size averaged 3.6 ± 0.4 cm^2 (range, 1.9-6.5 cm^2) and was significantly greater in patients with autologous chondrocyte transplantation (5.1 ± 1 cm^2) compared with osteochondral autograft transfer (2.4 ± 0.2 cm^2, $P < .05$) or microfracture (3.2 ± 0.4 cm^2, $P < .05$). Mean duration of symptoms before surgery was 21 ± 3 months (range, 1-48 months) (Table 1). Single articular cartilage lesions were treated in 55% of studies, and multiple lesions were present in 45%. Eleven studies included defects of the femoral condyle only, whereas 9 studies treated defects in both the patellofemoral and tibiofemoral compartments. Fifty percent of studies included patients with concomitant procedures. Fifteen studies reported on individual surgical techniques, and 5 studies were comparative studies. Twelve studies reported information on microfracture, 7 on autologous chondrocyte transplantation, 5 on osteochondral autograft transfer, and 1 on osteochondral allograft transplantation.[#] Limited data on sports participation were available after osteochondral allograft transplantation. Four studies were randomized controlled studies, 3 were prospective cohort studies, 1 was a case control study, 12 were prospective case series, and 1 was a retrospective case series. Level-of-evidence rating showed 4 studies at level 1, 3 at level 2, 1 at level 3, and 12 at level 4. Average Coleman methodology score (69.8 ± 3.5; range, 22-100) was significantly higher than that reported for cartilage repair in general (43.5 ± 1.6, $P < .0001$) by Jakobson et al.[19] Coleman methodology scores showed an inverse correlation with the level-of-evidence rating ($r = -.674$, $P < .001$). Coleman methodology scores were 65 ± 6 for microfracture studies, 77 ± 5 for studies involving autologous chondrocyte transplantation, and 71 ± 2 for studies describing results after osteochondral autograft transfer without significant difference in methodological quality between the surgical techniques. Despite variability between the Coleman methodology subscores of the individual cartilage techniques, the differences were not statistically significant (Figure 1).

Good and excellent results were reported on average in 79% ± 5% of athletes. Rating was good and excellent in 67% ± 7% after microfracture, in 82% ± 7% of autologous chondrocyte transplantation patients, and in 93% ± 5% of patients treated with osteochondral autograft transfer ($P = .01$ osteochondral autograft transfer versus microfracture). Postoperative Lysholm scores after articular cartilage repair in athletes averaged 88 ± 2 points. Significant increases in KOOS subscales for sports and recreation were observed after microfracture (19-point increase), autologous chondrocyte transplantation (36 points, $P < .05$ versus microfracture), and osteochondral allograft transplantation (28 points).[33,48] Comparison of microfracture and autologous chondrocyte transplantation showed higher increases in KOOS sports and recreation scores after chondrocyte transplantation at 36 months.[48] An increase in Tegner activity scores was observed in 84% ± 6% of all patients after articular cartilage repair. The average postoperative Tegner score was 6.1 ± 0.4, and the highest average Tegner scores were found after autologous chondrocyte transplantation (Figure 2A). Decreasing Tegner scores were observed after the initial increase in 6 studies (33%) after cartilage repair in athletes. Decreasing activity scores were observed in 5 studies (42%) after microfracture and occurred in 47% to 80% of individuals between 24 and 36 months postoperatively. Decreasing activity scores were also seen in 1 study (20%) between 2 and 7 years after osteochondral autograft transfer. The decreased activity scores were still higher than the preoperative scores for both surgical techniques. No decrease of postoperative

[#]References 2, 7, 14-16, 21, 25, 26, 30, 31, 33, 36, 37, 39, 40, 44-46, 48, 50

TABLE 1
Study Data Overview[a]

	Overall	MF	ACT	OAT
Patients, n	1410	787	362	261
Age, y	29 ± 6	31 ± 2	28 ± 4	27 ± 2
Follow-up, mo	42 ± 3	42 ± 5	42 ± 3	42 ± 10
Lesion type, %				
Single only	55	66	57	100
Single and multiple	45	33	43	0
Traumatic only	65	75	86	0
Traumatic and degenerative	35	25	14	100
Lesion location, %				
Femorotibial only	55	42	29	100
Femorotibial and patellofemoral	45	58	71	0
Lesion size, cm^2	3.6 ± 0.4	3.2 ± 0.4	5.1 ± 0.8[b]	2.4 ± 0.2
Duration of sypmtoms, mo	21 ± 3	24 ± 7	23 ± 3	21 ± 1
Concomitant procedures, %	50	42	57	60

[a]MF, microfracture; ACT, autologous chondrocyte transplantation; OAT, osteochondral autograft transfer.
[b]$P < .05$: ACT versus OAT and ACT versus MF.

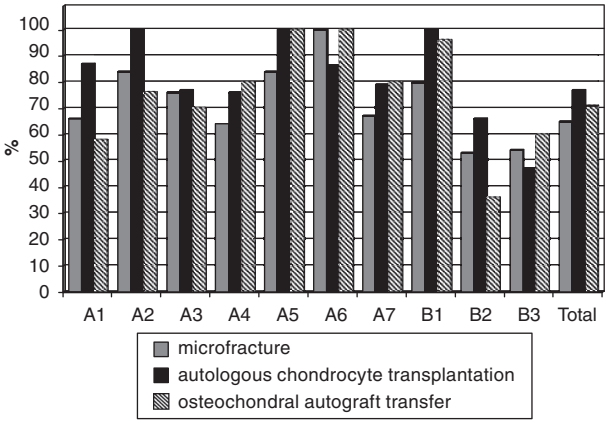

Figure 1. Average Coleman methodology total scores and subscores, parts A and B: A1, study size; A2, follow-up; A3, concomitant surgical procedures; A4, study design; A5, diagnostic certainty; A6, surgical technique; A7, rehabilitation; B1, outcome criteria; B2, procedure of outcome assessment; B3, patient selection process. Because maximal scores vary from 5 to 15 points between subscores, results are displayed as percentage of maximum value, for better comparability.

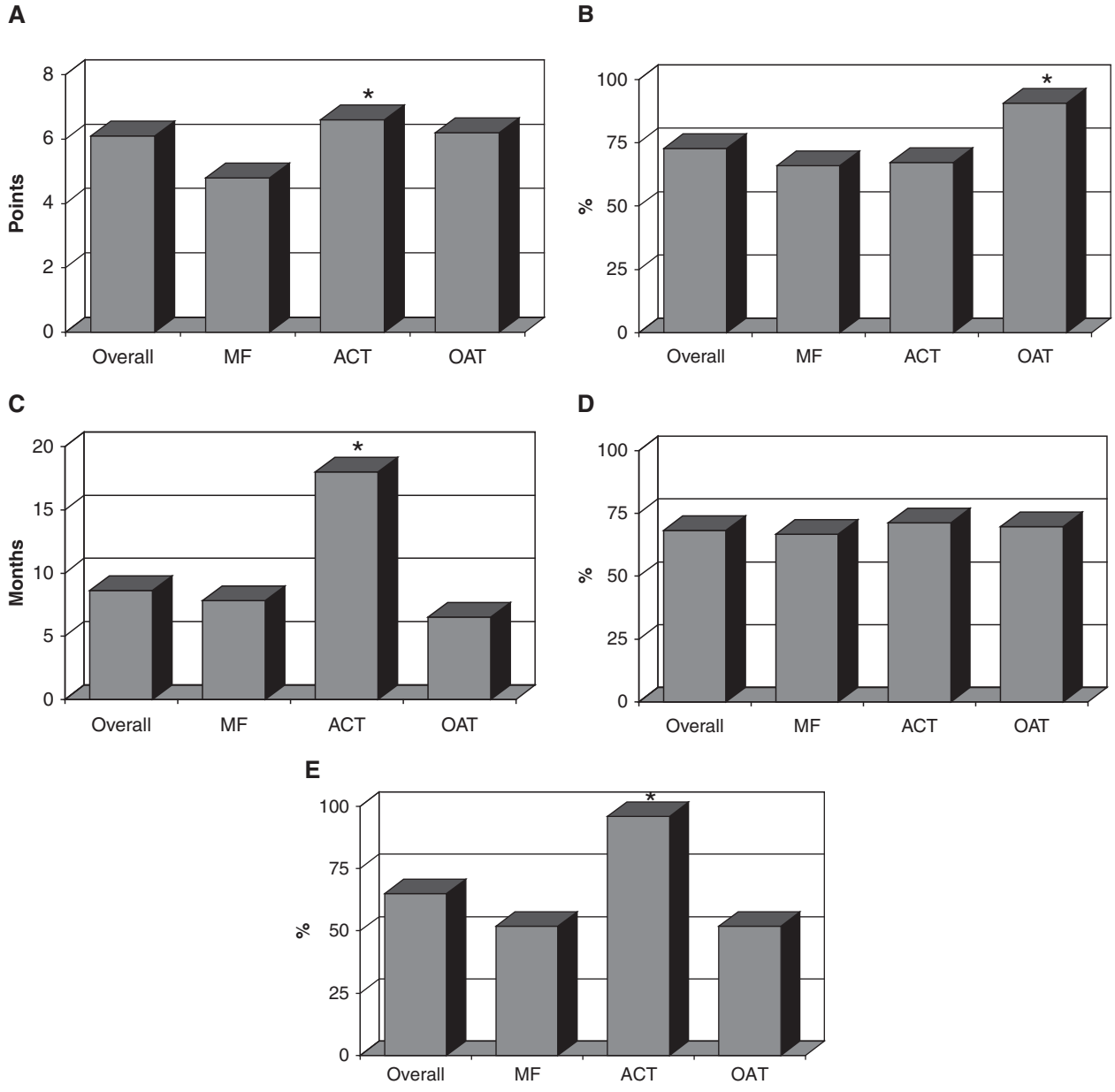

Figure 2. Bar graphs demonstrating the results after cartilage repair overall, microfracture (MF), autologous chondrocyte transplantation (ACT), and osteochondral autograft transfer (OAT): A, Tegner activity scores ($P < .05$, ACT versus MF); B, rate of return to sport ($P < .05$, OAT versus MF); C, time to return to sport ($P < .001$, ACT versus OAT and MF); D, rate of return to preinjury level sports; E, rate of continued sports participation ($P < .01$, ACT versus MF).

activity scores was observed 36 to 60 months after autologous chondrocyte transplantation.[25,26,36,37,45,50]

Return to sports participation averaged 73% ± 5% overall, with return rates of 66% ± 6% (range, 44%-100%) for microfracture, 67% ± 17% (range, 33%-96%) for autologous chondrocyte transplantation, and 91% ± 2% (range, 86%-94%) for osteochondral autograft transfer ($P = .01$, osteochondral autograft transfer versus microfracture) (Figure 2B). There was a notable absence of specific information on return to sports after osteochondral allograft transplantation in the reviewed literature. There was no statistical correlation between rate of return to sport and level of evidence ($r = .234$, $P = .38$) or Coleman methodology score ($r = –.189$, $P = .52$). Time to return to sports participation ranged between 7 and 18 months depending on the cartilage repair technique. Average time to return to sport was 8 ± 1 months (range, 2-16 months) after microfracture, 7 ± 2 months (range, 4-11 months) after osteochondral autograft transfer, and 18 ± 4 months (range, 12-36 months) after autologous chondrocyte transplantation (Figure 2C). Return to sport at the preinjury level was possible at an average of 68% ± 4% (range, 33%-100%) without significant difference

between microfracture (68% ± 5%; range, 50%-100%), autologous chondrocyte transplantation (71% ± 12%; range, 45%-100%), and osteochondral autograft transfer (70% ± 3%; range, 63%-73%) (Figure 2D). Continued sports participation at the preinjury level was observed in 65% ± 8% (range, 35%-100%) after average follow-up of 50 ± 7 months (range, 24-84 months). The best durability was reported after autologous chondrocyte transplantation (96% ± 4%) compared with microfracture (52% ± 6%, $P = .002$) and osteochondral autograft transplantation (52% ± 21%, $P = .079$) (Figure 2E). Whereas only 52% of athletes continued to perform at their preinjury level 7 years after osteochondral autograft transfer, 79% of athletes were still participating in their sport when lower-level participation was included.

Several factors were found to influence the ability to return to sports after articular cartilage repair in the knee (Table 2). Younger age resulted in better rates of return to sport participation with all surgical techniques. The reported age threshold for increased return to sports varied between 25 and 40 years.[15,21,31,37,39] Sixty-five percent of athletes younger than 40 years of age returned to sports after microfracture, compared with 20% of older patients.[39] Similarly, 71% of athletes younger than 25 years returned after chondrocyte implantation, compared with 29% above that age threshold.[37] Age dramatically affected return to sports after osteochondral autograft transfer, with 90% of athletes younger than 30 years returning to full sports participation; in contrast, only 23% of older athletes returned to preinjury participation, with 70% of older athletes returning to lower-level sports.[21] The time between diagnosis and surgical treatment of the cartilage defect also significantly affected the ability to return to sport. Athletes who were symptomatic for fewer than 12 months returned to sports in 66% of cases after microfracture and 67% after autologous chondrocyte transplantation.[37,39] However, the return rates declined to 14% ($P < .01$) and 15% ($P < .05$), respectively, if preoperative intervals exceeded 12 months. In fact, an inverse statistical correlation was demonstrated between preoperative duration and return to sport after chondrocyte transplantation ($P < .05$).[37] The most dramatic effect of the preoperative duration was seen in adolescent athletes. All athletes returned to sport if time to chondrocyte transplantation was less than 12 months, but only a third of the athletes were able to return with longer preoperative intervals ($P < .01$).[36] Better clinical results were described with acute lesions, compared with chronic lesions, after osteochondral autograft transfer; in addition, chronic lesions with radiographic signs of joint degeneration predicted limited return to sports after this technique.[21,31] Lesion size of less than 2 cm^2 was associated with a significantly higher rate of return to sports when compared with larger lesions after microfracture ($P < .05$) and osteochondral autograft transfer ($P < .05$).[15,31,39] In comparison, no significant effect of lesion size on return to sport was noted after autologous chondrocyte transplantation. The type of cartilage defect also had an influence on the outcome, with significantly better results demonstrated in chondral defects compared with osteochondral defects after microfracture and osteochondral autograft transfer ($P < .01$).[15,16] Lesion location was also found to be relevant for some cartilage repair techniques. Better clinical outcome and more consistent return to sports was observed with lesions on the lateral femoral condyle after osteochondral autograft transfer ($P < .01$),[31] whereas worse results were obtained for defects of the central aspect medial femoral condyle after microfracture ($P < .05$).[15] The average number of prior surgeries was lower in athletes who returned to sports participation after microfracture and autologous chondrocyte transplantation.[37,39] Eighty-six percent of athletes undergoing microfracture as a first-line procedure were able to return to sport, compared with 33% with prior surgeries.[39] Return to sports was significantly better in competitive athletes (range, 71%-83%) than recreational athletes (range, 16%-29%) after microfracture and chondrocyte transplantation ($P < .01$), but no difference was observed with osteochondral autograft transfer. Time to return to sports was significantly shorter in competitive athletes (14 months) than in recreational athletes (22 months, $P < .01$) after autologous chondrocyte transplantation. Concomitant procedures such as meniscectomy, ACL reconstruction, and osteotomy did not negatively affect outcome after autologous chondrocyte transplantation, whereas simultaneous adjuvant procedures were associated with better results after osteochondral autograft transfer and microfracture.[2,30,31,37]

TABLE 2
Factors Affecting Return to Sport After Cartilage Repair[a]

	MF	ACT	OAT
Age	+	+	+
Duration of symptoms	+	+	+
Lesion size	+		+
Lesion type	+		+
Lesion location	+		+
Number of previous surgeries	+	+	
Athlete's skill level	+	+	
Concomitant procedures	+		+
Repair tissue morphology	+		+

[a]Plus sign (+) indicates demonstrated effect on return to sport. MF, microfracture; ACT, autologous chondrocyte transplantation; OAT, osteochondral autograft transfer.

Macroscopic and microscopic data on cartilage repair tissue in athletes was available in 6 studies.[2,14-16,44,45] Macroscopic evaluation showed normal or nearly normal repair tissue in 79% after osteochondral autograft transfer, compared with 45% after microfracture. Although all athletes with normal or nearly normal repair tissue were able to return to preinjury activity levels, only 36% of athletes with abnormal repair tissue were able to return ($P < .001$). Limited fill grade with exposed subchondral bone was observed more frequently in recreational athletes (35%) compared with competitive athletes (8%, $P = .019$) after microfracture.[2] Histologic evaluation showed normal hyaline tissue after osteochodral autograft transfer and predominantly fibrohyaline tissue after microfracture without association between histological tissue quality and return to sport in the reviewed studies.[2,14-16,44] Better overall

histological assessment ($P < .05$) and histomorphometric scores, including higher proteoglycan content, higher type II collagen content, and more normal chondrocyte morphology ($P < .01$), were seen after characterized autologous chondrocyte implantation compared with microfracture at 12-18 months.[45] However, whether the histological superiority leads to improved return to sports after characterized autologous chondrocyte transplantation remained inconclusive.

No significant technique-specific complications were reported for microfracture or osteochondral autograft transfer in athletes. Graft hypertrophy was observed in 15% to 28% of athletes after autologous chondrocyte transplantation. Traumatic delamination from graft hypertrophy was responsible for up to 50% of failures after knee articular cartilage repair with autologous chondrocyte transplantation in high-impact athletes.[37,50]

DISCUSSION

Whereas previous studies have demonstrated improved joint function after articular cartilage repair procedures in the knee, no systematic information has been reported on the ability of articular cartilage repair to return the injured athlete to demanding sports participation. This lack of information about postoperative sports participation is surprising when considering that (1) athletes often consider return to sports the most important outcome measure for successful treatment and (2) discussion of the possibility to return to sports is a regular topic during the preoperative counseling of the athlete. Evaluating articular cartilage repair procedures in the high-impact athletic population also provides important information about the ability of these techniques to restore articular cartilage in the knee to the degree that it can withstand maximum mechanical demands. To address this lack of information, we systematically reviewed all studies that provided information on sports activity after cartilage repair. Our systematic review, comprising 20 studies with predominantly prospective study design and more than 1300 patients, provides comprehensive information on sports participation after articular cartilage repair. Coleman methodology scores were significantly higher for studies included in our review than for cartilage repair studies reported previously, attesting to the quality of the included studies.[8,19] The high Coleman methodology subscale scores observed in our review for study type, outcome assessment, and outcome criteria further support our study quality. Therefore, our study provides a comprehensive, high-quality review and provides valuable information on the efficacy of articular cartilage repair that is relevant for both the athlete and the clinician.

The high postoperative Lysholm scores, high portion of good and excellent ratings, increased KOOS sports and recreation subscores, and improved Tegner activity scores observed in our study confirm that articular cartilage repair procedures improve activity levels even under high mechanical demands. Following the initial improvement, a decrease in Tegner activity scores was noted in several studies 2 to 3 years after microfracture[14-16,25,39] and in one study 7 years after osteochondral autograft transfer.[30] Despite the decrease in score, Tegner activity scores with both techniques remained higher than before surgery. The reasons for this functional decline are unknown. Repair cartilage fill volume has been shown to play a critical role in durability of the functional improvement after cartilage repair in the knee, and limited cartilage fill may be a factor responsible for the observed decline of activity scores.[38] This is consistent with the observation that deterioration of knee function occurred primarily in athletes with poor repair cartilage morphology and fill after microfracture.[2] However, decreasing knee function was observed not only in patients with poor fill grade, and other factors must be considered. Limited peripheral integration with the surrounding articular cartilage increases vertical shear stresses between repair and native cartilage and promotes cartilage degeneration. Limited peripheral integration has been observed after microfracture and osteochondral autograft transfer and may provide an explanation for the decreasing Tegner scores.[38] What may also cause deterioration is the relative thinning of the overlying repair cartilage tissue from subchondral bone overgrowth following microfracture and from a mismatch of donor-recipient cartilage thickness after osteochondral transfer, especially in a population that regularly participates in high-impact activities.[30,38] Additional systematic study is required to further evaluate the factors leading to the decrease in function described after these 2 techniques in athletes. In comparison, no functional decline was observed 3 to 5 years after first- or second-generation autologous chondrocyte transplantation.[25,36,37,45] This is consistent with the good long-term functional improvement and repair cartilage characteristics found up to 11 years after autologous chondrocyte transplantation.[42] The continuation of sports participation in 96% at 3 to 5 years after autologous chondrocyte transplantation observed in our study further supports the excellent durability of this repair technique.[25,26,39] Interestingly, 1 study found that sports participation after chondrocyte transplantation can improve postoperative knee function scores, demonstrating the benefit of athletic activity after chondrocyte transplantation.[26]

Our results show that articular cartilage repair in the knee of athletes can successfully return the athlete to demanding, high-impact sports participation. The average return rate of 73% in our study compares well with the rates reported after other common sports medicine procedures, such as ACL reconstruction and meniscal repair[5,6,32] (Table 3). The observed variability of return rates within the individual techniques has also been observed for other surgical procedures in athletes and likely resulted from mixed patient populations with variable athletic skill levels, patient demographics, and cartilage defect characteristics. The highest return rates were reported for osteochondral autograft transfer, with an average return rate of 91%. The fact that this minimally invasive technique is used to treat smaller defects, has a short postoperative rehabilitation, and does not require generation of cartilage repair tissue may explain the high return rate after this technique. Both microfracture and autologous chondrocyte

TABLE 3
Comparison of Return-to-Sport Rates (in Percentages)

Procedure	Return Rate (Range)
Anterior cruciate ligament reconstruction	71 (53-81)
Meniscal repair	74 (56-85)
Articular cartilage repair	73 (66-91)
Microfracture	66 (44-100)
Autologous chondrocyte transplantation	67 (33-96)
Osteochondral autograft transfer	91 (86-94)

transplantation were able to return about two-thirds of treated athletes back to sports participation. These similar rates of postoperative sports participation are consistent with the comparable clinical results recently reported for both techniques in a randomized comparison by Knutsen et al.[22,23] The fact that chondrocyte transplantation produced similar return rates is encouraging given that most athletes underwent chondrocyte transplantation as secondary treatment of often large cartilage lesions. The good return rate in these challenging revision cases was also reflected in the improved KOOS sports and recreation scores reported in the Study of the Treatment of Articular Repair (STAR) trial of autologous chondrocyte transplantation.[50] The different surgical techniques achieved equal rates of return to sports participation at the preinjury level. These results are encouraging when considering the high demands placed on the repaired cartilage defects in high-level competitive athletes. Interestingly, a recent study in professional basketball players indicated that although the athlete returns to sport at the preinjury level, some performance parameters may still be decreased following the initial return to competition.[7,40] Similar performance limitations have been described for professional football players after ACL reconstruction.[5] In that study, pain, stiffness, deconditioning, and altered joint proprioception were responsible for the decreased performance and may explain the decreased performance in professional basketball players after microfracture. Quadriceps inhibition from intra-articular effusion following the initial return to high-impact sports after cartilage repair may also contribute to initially limited performance after return to sport.[41]

Time to return to sport was shorter for osteochondral autograft transfer and microfrature than for chondrocyte implantation. The longer time to return to sport after autologous chondrocyte transplantation is not surprising and is based on the larger average lesion size, more invasive nature of this technique, and the duration of the repair cartilage growth and rehabilitation process. Accelerated rehabilitation programs have been recently described and may be able to shorten the time to return after this technique.[17]

In athletes who returned to sports, the ability to continue participation at the preinjury level after 3 to 5 years was markedly better after autologous chondrocyte transplantation than with microfracture or autologous osteochondral transfer. This is consistent with the absence of functional score deterioration after autologous chondrocyte transplantation and confirms the previously described excellent long-term durability of the functional improvement from this repair technique even under high demands.[42] The unsustained improvement after microfracture in some patients has been attributed to the limited fibrohyaline repair tissue quality and variable fill volume after this marrow stimulation technique.[2,37,46] Limited defect fill from settling of the transferred cylinder, incomplete peripheral repair cartilage integration, relative thinning of the repair cartilage owing to donor-recipient mismatch, and subchondral sclerosis have been described 7 years after osteochondral transfer and may be responsible for the limited durability after this technique.[30] Socioeconomic and psychological factors, such as the fear of reinjury, have been shown to affect return to sport after ACL reconstruction[13] and may contribute to the observed reduction of activity in athletes after articular cartilage repair. Our systematic review was able to identify several factors that affect the return to sports participation after articular cartilage repair in the knee. The reasons athletes return to sports and continue participation are certainly multifactorial, and further systematic study is needed to evaluate the influence of nonclinical factors on sports participation after articular cartilage repair.

The athlete's age was found to significantly affect sports participation after all cartilage repair techniques. A possible explanation for the better return rate in younger athletes is offered by the age-dependent qualitative and quantitative difference in metabolic activity and matrix synthesis in the repair cartilage.[47,49] A slower overall recovery in older patients has also been suggested.[21] In addition, work demands and family obligations have likely contributed to the lower rate of return to demanding athletic activity in older athletes.

The length of the time interval between injury and treatment was also found to be an important factor influencing return to sports after articular cartilage repair. Several studies reported a time threshold of 12 months after injury.[37,39] The rate of return increased fivefold for microfracture and up to threefold for autologous chondrocyte transplantation if surgery was performed within 1 year of the cartilage injury.[36,37,39] Our results suggest that untreated cartilage defects may create an unfavorable environment for subsequent cartilage repair. This is consistent with the previously reported inferior macroscopic repair cartilage quality associated with prolonged preoperative intervals, and it offers an explanation for the inferior results from delayed cartilage repair observed in this and other studies.[2,37] The lower return to full athletics associated with preoperative radiographic joint degeneration after osteochondral autograft transfer also supports this conclusion.[21] Prolonged preoperative absence from athletic activity has been shown to decrease sports participation after delayed ACL reconstruction, which provides another plausible reason for the decreased return rate after delayed cartilage repair.[13] Selection bias may also contribute to this observed effect; that is, patients with longer preoperative intervals may have failed prior surgeries, which may predispose them to

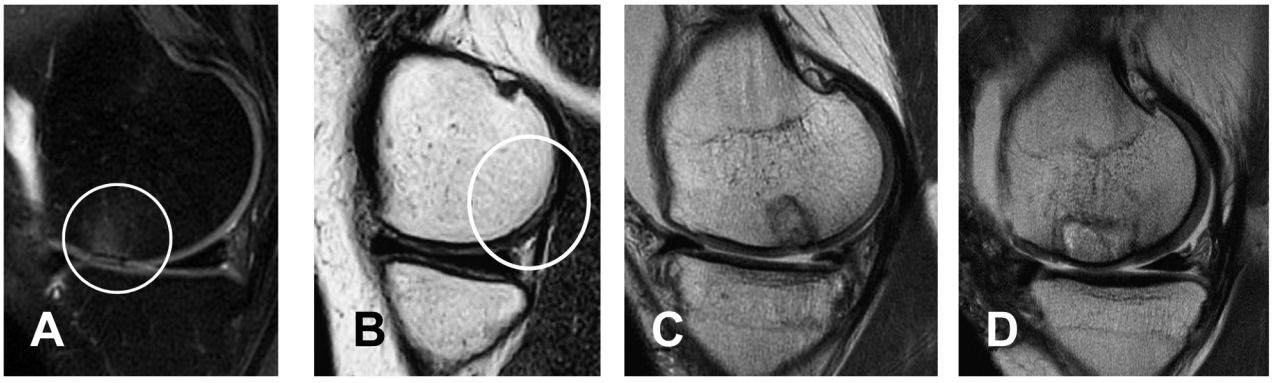

Figure 3. Postoperative magnetic resonance images demonstrating successful articular cartilage repair in athletes who returned to sport after microfracture (A), autologous chondrocyte transplantation (B), osteochondral autograft transfer (C), and osteochondral allograft transplantation (D).

less favorable outcomes.[35] As such, our results emphasize the importance of early surgical treatment of articular cartilage lesions for the successful postoperative return to sports participation.

Athletes without prior surgical intervention were more likely to return to high-impact sports after microfracture.[39] The number of prior surgeries inversely correlated with return to preinjury athletics after autologous chondrocyte transplantation.[36] Longer preoperative intervals in athletes that had failed surgical intervention may explain the lower postoperative rate of return to sports. However, structural changes in the subchondral bone from prior procedures may also affect the success rate after secondary cartilage procedures.[35] Nevertheless, our data show that even in the revision setting articular cartilage repair can successfully return players to competitive high-impact sports participation.[36,37]

Return to recreational sport after articular cartilage repair in the knee was lower than return at the competitive level. Higher return rates have also been reported for elite athletes after ACL reconstruction.[13] Delayed diagnosis and longer preoperative intervals have been suggested as potential causes for the lower return to sport in recreational athletes.[37] These factors may also explain the better defect fill observed in competitive athletes.[2] Younger age, higher motivation to return to sport in professional athletes, and the improved access to postoperative rehabilitation likely also contribute to the increased return rates in elite players, whereas changing social demands and avoidance of additional injuries may have contributed to the low return rate in recreational players.[2,13]

Lesion characteristics also influenced the return to sports activity. Defect size less than 2 cm^2 was associated with a significantly higher rate of return to high-impact athletics after microfracture and osteochondral autograft transfer,[31,39] whereas no association was found between defect size and autologous chondrocyte transplantation. This is not surprising, because both microfracture and osteochondral autograft are indicated primarily for smaller defects whereas autologous chondrocyte transplantation has been used for both small and large cartilage defects.[22,23,37,42]

Articular cartilage defects of the knee are frequently associated with other pathologic conditions, and addressing the combined pathology is critical for the success of the cartilage repair procedure.[23,29,37,42] Little information is available on how adjuvant procedures affect the ability to return to sport after cartilage repair. Previous studies have reported a limited return to sports activity after combined ACL reconstruction and high tibial osteotomy.[4] Simultaneous adjuvant procedures did not negatively affect the ability to return to sport after autologous chondrocyte transplantation.[37] In fact, concomitant procedures were found to improve the results after microfracture; they even increased the rate of unrestricted sports participation after osteochondral autograft transplantation.[2,30] These findings suggest that concomitant pathology should be treated simultaneously with articular cartilage repair to optimize the athlete's return to sport. Addressing combined pathologies in a single stage will avoid repeated rehabilitation and extended absence from sport and their negative effects on postoperative sports participation.

Complications were rare after microfracture and osteochondral autograft transfer, which is consistent with the limited invasiveness of these techniques. Traumatic graft delamination was observed in athletes after autologous chondrocyte transplantation and can result from the high-impact loading in the presence of a hypertrophic graft. Routine magnetic resonance imaging to evaluate for graft hypertrophy before returning the athlete to demanding impact activity has been recommended to decrease the risk of traumatic delamination (Figure 3). If graft hypertrophy is detected, restricted progression of joint loading activities or prophylactic arthroscopic chondroplasty may be indicated.[37] Substituting the periosteum with a collagen membrane or using second-generation chondrocyte implantation techniques can reduce the incidence for graft hypertrophy and should be considered in this specific population.[1,25]

In conclusion, the results of articular cartilage repair in the athlete's knee are encouraging and comparable to other common sports medicine procedures. Return to sports participation can be successfully achieved by microfracture,

autologous chondrocyte transplantation, and osteochondral autograft transfer. Insufficient information is available at this time for osteochondral allograft transplantation. Athletes are often able to return to sports participation at the preinjury level, even at the competitive high-impact level. Highest return rates can be achieved with osteochondral autograft transfer, although best durability is seen after autologous chondrocyte transplantation. Younger competitive players with small defect size, short duration of symptoms, and fewer prior surgical interventions have a higher probability to return to sports. Better repair cartilage tissue also results in higher ability to return to sports, emphasizing the importance of repair tissue quality. Further systematic study is necessary to better explain lack of return to sport and the unsustained sports participation observed in some patients. In addition, prospective long-term studies are needed to determine if articular cartilage repair in athletes can influence the high incidence of osteoarthritis associated with high-impact sports.

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